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AN INVENTORY OF EMBEDDEDNESS OF SALMONID HABITAT

in the

SOUTH FORK SALMON RIVER DRAINAGE, IDAHO

by

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Payette and Boise National Forests

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INTRODUCTION

Comparison of fish habitat condition among various locations within the South Fork Salmon River drainage (South Fork) is necessary in order to facilitate development of future management objectives for the aquatic ecosystem. The single most significant element of fish habitat management during recent history has been development of objectives for limiting the deposition of fine sediment. Four environmental impact statements within the drainage during the past decade (Anon., 1977, Anon., 1979a, Anon., 1979b. and Anon., 1981) have all dealt with the impact of sediment on fish habitat as a major issue. The development of another environmental impact statement pursuant to the implementation of the National Forest Management Act of 1976 (36 CFR 1950) is presently underway.

Embeddedness is generically defined as the amount of fine sediment which is deposited in the interstices between larger stream substrate particles. This fish habitat characteristic has been demonstrated by research (Klamt, 1976, Kelly and Dettman, 1980) to negatively influence the ability of a stream to rear fish. Increasing the amount of deposition, embeddedness, decreases the number of fish a stream can rear.

This inventory of embeddedness of fish habitat was conducted in order to empirically answer three questions.

1) Is it feasible to limit development, such as road building, so that no significant impact to fish habitat occurs?

2) Does the method of measure used for this inventory provide data which is quantitatively comparable to other commonly accepted methods such as core sampling?

3) Is the method of measure sensitive enough to detect individual sources of deposited fine sediment, so that it could be used to monitor future land disturbance?

STUDY AREA

The South Fork Salmon River drainage is approximately 800,000 acres in Central Idaho. Approximately two-thirds of this acreage is managed by the Payette National Forest and about one-third is managed by the Boise National Forest. Much of the history of this area has been summarized by Megahan, Platts and Kulesza (1980).

Nineteen tributary drainages to the South Fork of similar acreage were chosen to represent the full range of past development (Table 1). These tributaries were later grouped into three catagories of development and have characteristics which can be quantified during future analyses. All streams drain steep fluvial lands (Anon., 1969, Anon., 1970, Thompson, Skabelund, and Kulesza, 1973.). Completely "undeveloped," unroaded, drainages such as Blackmare, Caton, and Fourmile Creeks were chosen because they were intermingled with heavily "developed" or roaded

Table 1. Location of embeddedness samples taken from tributaries of the South Fork Salmon River. These streams are of similar size and gradient with a large portion of each drainage in fluvial granitic landtypes.

Location	Township	Section	Range	Description
Bear Creek	20N	5NE¼	7E	At trail crossing
Blackmare Creek	17N	10SE¼	6E	Upstream from old road
Buckhorn Creek	18N	4SW¼	6E	20m upstream from South Fork
Camp Creek	18N	15 SW¼	6E	50m Downstream from FS road 674 bridge
Caton Creek	19N	34NW¼	7E	200m upstream from East Fork
Cougar Creek	18N	21NE¼	6E	100m upstream from South Fork
Cow Creek	20N	19NE¼	6E	Upsteam from first culvert
Dollar Creek	16N	14SW¼	6E	Upstream from bridge
Elk Creek	21N	22NE¼	7E	Upstream from FS road 340 bridge
Fitsum Creek	19N	9NE¼	6E	100m upstream from South Fork
Fourmile Creek	18N	26NW¼	6E	Upstream from FS road 674 culvert
Goat Creek	17N	7NW¼	7E	100m upstream from FS road 674 culvert
Lick Creek	20N	18SE¼	6E	Upstream from old bridge location
N.F. Fitsum Creek	19N	8NW¼	6E	Upstream from FS trail 087
N.F Lick Creek	20N	13NE¼	5E	200m upstream from FS road 48 bridge
Parks Creek	19N	30NW¼	8E	50m downstream from FS road 48 culvert
Pony Creek	21N	2SW¼	7E	Downstream from FS road 340 bridge
Porhyry Creek	22N	9NE¼	8E	50m upstream from South Fork
Zena Creek	20N	28NW¼	6E	20m upstream from reservoir highwater

drainages such as Dollar Creek, Buckhorn Creek, Cow Creek, and Zena Creek. Undeveloped and developed drainages are not geologically limited to "corners" of the South Fork. This factor limits confounding of results due to climatic or geologic variation. "Partially developed" drainages included those with low road mileage such as Lick Creek, Pony Creek, and Elk Creek.

Eleven areas were chosen in order to compare the method of measure utilized in this inventory to core sampling (Table 2). These 11 areas represent major summer chinook slamon (Oncorhynchus tshawytscha) spawning habitat where core sampling has been conducted by Corley and Newberry (1982) and Lund (1982).

Eight areas were chosen in order to determine whether existing sources of man-caused fine sediment could be detected (Table 3). Recently an open-pit mine was authorized by the Forest Service (Anon., 1981) in West End Creek, a tributary to Sugar Creek which is a tributary to the East Fork of the South Fork Salmon River (East Fork). Locations were established in Sugar Creek and the East Fork, both upstream and downstream from the influence of the open-pit mine. Other sample locations were chosen in geologically similar drainages (Knight, Thompson, Kulesza, and Dean, 1974.), Profile Creek, Quartz Creek, and Tamarack Creek, in order to act as controls.

Table 2. Location of embeddedness samples taken from major spawning areas of the South Fork Salmon River. These sites are close to locations core sampled by Lund (1984), and Corley and Newberry (1982).

Location	Township	Section	Range	Description
Burgdorf	22N	1SW¼	4E	In Lake Creek 50m upstream of bridge to Guard Station
Chinook	22N	26SW¼	5E	In Secesh River 200m upstream of FS campground
Corduroy	23N	10SE¼	4E	In Lake/Corduroy Creek 200m upstream of FS road 246 bridge
Dollar	16N	14SE¼	6E	In the South Fork downstream of bridge
Glory	19N	16NE¼	6E	In the South Fork 200m upstream from old USGS flow gage
Ice Hole	18N	20 Center	8E	In Johnson Creek 50m upstream from where Johnson Creek flows easterly toward FS road
Oxbow	18N	15SW¼	6E	In South Fork 100m upstream from "Oxbow breach"
Poverty	17N	10NE¼	6E	In South Fork on most downstream area of Poverty spawning flat
Secesh Bridge	22N	23NW¼	5E	In Sesech River 300m upstream of FS road 21 bridge
Stolle	14N	1NW¼	6E	In South Fork 100m upstream from FS grazing enclosure
Threemile	23N	26NW¼	4E	In Lake Creek 100m downstream from old placer mining.

Table 3. Locations of embeddedness samples taken from the East Fork South Fork Salmon River (EF) vicinity. These locations were picked to "bracket" sediment input from an active open-pit mine near Stibnite, Idaho, in West End Creek (WE).

Location	Township	Section	Range	Description
EF downstream from Sugar Creek	19N	34 Center	9E	Pool tailout in EF 200m downstream from Sugar Creek.
EF upstream from Sugar Creek	19N	34SE¼	9E	In EF 20m upstream for Sugar Creek
EF upstream from Vibika Creek	19N	27NW¼	8E	In EF 10m upstream from Vibika Creek
Profile Creek	19N	25NW¼	8E	In Profile Creek 100m upstream from FS road 48 bridge
Quartz Creek	19N	21NE¼	8E	In Quartz Creek 200m upstream from E
Sugar Creek downstream from WE	19N	34SE¼	9E	In Sugar Creek upstream for FS road 48 bridge
Sugar Creek upstream from WE	19N	35SE¼	9E	In Sugar Creek 30m upstream from WE
Tamarack Creek	19N	29NW¼	9E	In Tamarack Creek upstream from FS road 48 bridge

METHODS

Methods for this inventory were adapted from Kelly and Dettman (1980) and data acquired could be entered into the General Aquatic Wildlife System (GAWS) of Region Four of the USDA-FS.

Embeddedness was earlier defined in generic terminology. For the remainder of this report embeddedness refers specifically to the proportion of a matrix particle (4.5 - 30.0 cm greatest diameter) surrounded by fine sediment (6.3 mm dia.). The proportion is calculated from the formula (see also Fig. 1):

$$E = \frac{d_2}{d_1} (100),$$

Where; E = (percent) embeddedness,
d_1 = the longest diameter of a matrix particle (4.5 - 30.0 cm greatest diameter) at right angles to the plane of deposition of fine particles ($<$ 6.3mm dia.), and,
d_2 = the distance along d_1 covered by fine sediment ($<$ 6.3 mm dia.) or "embedded" in the stream bottom.

The characteristic of embeddedness that is of critical consideration is that it is the proportion of a single matrix particle as measured. A population of single matrix particles must be sampled in order to characterize fish habitat conditions in a quantitatively precise manner.

I wanted to report measurement and subsequent statistics in two significant figures, to the nearest whole percentage. I used 4.5 cm to approximate the smallest total length measurement. The second significant figure in this instance is defined by 0.1 cm. The standard of measurement for d_1 and d_2 was established as the closest millimeter.

I defined how many samples were required from each population characterized by the study. Very little data was available that could characterize variability of precise embeddedness measurements, so I applied some general rules. The first rule of thumb is that 30 samples are generally required to characterize a parametric mean. The second rule of thumb is that precise ($\pm$ 10 percent of estimate) estimates from binomial populations can be obtained from about 100 samples. A sample size of 100 was selected as a minimum number of measurements for each population or location sampled.

Sampling required use of several tools. A 60 cm steel hoop (Kelly and Dettman, 1980) was used to define particles to be measured. A 30 cm transparent ruler graduated in millimeters was used to measure greatest particle diameter, d_1, d_2, and water depth. A float and stop watch were used to measure water velocity. A steel pry bar (45 cm long) was necessary to dislodge stream bottom particles. Chest waders and shoulder length rubber gloves were used to keep dry and avoid hypothermia. Data and observations were recorded on a field form made of write-in-the-rain paper.

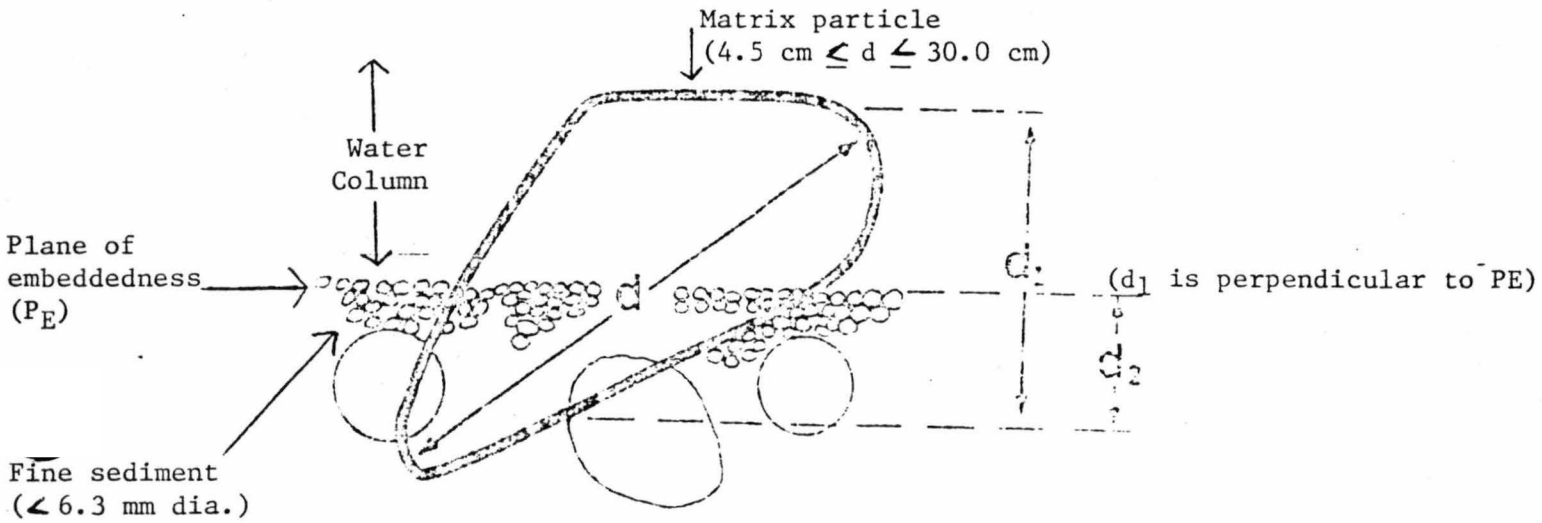

Figure 1. Embeddedness ($E = \frac{d_2}{d_1}(100)$) is defined in this 1983 South Fork Salmon River survey as the percentage derived from the longest diameter (d_1) of a matrix particle which is perpendicular to the plane of embeddedness (P_E) divided into the portion (d_2) of the length which is below the plane of embeddedness. A matrix particle is one which has its greatest diameter (d) between 4.5 cm and 30.0 cm. The plane of embeddedness is formed by fine sediment (< 6.3 mm dia.) surrounding some portion of the matrix particle.

Samples were taken systematically from each location in order to minimize the number of variables influencing measurement. Fish habitat was defined consistently among locations which would later be compared. All locations were sampled during base flow conditions in September and October 1983. Criteria used to define fish habitat were developed from Bovee (1978) and further refined for this study.

Upon arriving at each location (Tables 1, 2, & 3) the 60 cm steel hoop was randomly thrown into an area which had generally laminar flow across at least the hoop diameter. Samples were not taken from fluvial granitic tributaries (Table 1) or the East Fork (Table 3) if:

1) Float time across the hoop diameter was less than 0.9 seconds or greater than 2.5 seconds or,

2) water depth was less than 15 cm or,

3) the hoop or part of the hoop was in an eddy caused by a pool or large boulder or,

4) particles in the hoop were all less than 4.5 cm or greater than 30 cm. These criteria eliminated sites that did not approximate rearing habitat for juvenile steelhead trout.

Samples were not taken from spawning areas (Table 2) where:

1) Water depth was less than 30 cm or,

2) core sampling had disturbed the site or,

3) spawning activity had occurred during 1983 or,

4) particles in the hoop were all less than 4.5 cm or greater than 30 cm, or

5) the hoop or part of the hoop was in an eddy caused by a pool or large boulder. These criteria eliminated sites that did not approximate spawning habitat for summer (spring) chinook salmon.

Beginning at one side of the hoop and working across it, each free matrix particle (4.5 to 30.0 cm greater diameter), which had no fine particles ($\lesssim$6.3 mm diameter) surrounding it was lifted from the hoop, cursorily measured for d_1 and discarded. Measurement could be cursory for these particles because they show up as zeros in the data.

Starting back across the ring, matrix particles were then removed as systematically as possible. A matrix particle was generally picked up with my left hand (I am right handed) by grasping it with the thumb and index finger at the plane of embeddedness. I rotated the particle so that the embedded portion was to my left. My index finger was on the side of the rock away from my eye. I aligned my index finger with a point on the rock at the plane of embeddedness closest to me so that my right eye aligned the tip of my left index finger and the plane of embeddedness to form a straight line. Using only my right eye I placed the clear plastic ruler against the rock on the plane of embeddedness nearest me and aligned the zero on the ruler with the left margin of the rock. By sliding the ruler up and down I could pick the longest diameter of the particle which was perpendicular to the plane of embeddedness, while keeping the zero on the left margin of the rock. I considered misalignment and parallax to be sources of error in the measurement of d_1 and d_2. Misalignment should yield random error and parallax should be a source of systematic error. Neither should be significant sources of bias for comparison of relative values. Changes of hand position were occasionally made in order to move large rocks. Every particle exposed to the water column and meeting the criteria was measured until the hoop contained only a plane of particles greater than 30 cm and/or less than 4.5 cm diameter.

I then repeated throwing the hoop and taking measurements until 100 measurements had been taken. After taking 100 measurements I finished measuring all matrix particles in the last hoop in order to avoid bias against the most heavily embedded particles.

RESULTS

Developed vs. Undeveloped Drainages

Streams with watersheds which had been heavily roaded and logged were significantly more embedded than either undeveloped or partially developed areas. Streams with undeveloped and partially developed watersheds were not different.

The most heavily embedded streams were Cow and Dollar Creeks. They had 50 percent mean embeddedness (Fig. 2). At 19 percent mean embeddedness, Lick, Fourmile, and Elk Creeks were the least embedded.

A one-way analysis of variance was used to determine whether a significant difference existed between any of the means (Table 4). The probability that the means are equal was equal to, or less than 9 in 100,000 with 18 and 2027 degree of freedom ($F = 23.66$). The extremely significant F allows the use of the powerful least significant difference multiple range test to discriminate between individual means (Table 5). Those streams which are 40 to 50 percent mean embeddedness are significantly different than those with mean embeddedness less than 30 percent ($P = 0.05$).

Developed, partially developed, and undeveloped streams were grouped for a one-way analysis of variance (Table 6). Dollar, Cow, Cougar, Zena, Buckhorn, Fitsum, Camp, and the North Fork of Fitsum Creeks were grouped as developed. The partially developed group included Goat, Pony, Parks, Lick, and Elk Creeks. Caton, the North Fork of Lick Creek, Porphyry, Blackmare, Bear and Fourmile Creeks were grouped as undeveloped. The probability that the three groups have equal means is equal to or less than 9 in 100,000 with 2 and 2043 degrees of freedom ($F = 170.16$). Developed, partially developed, and undeveloped streams have mean embeddedness of 44, 24, and 24 percent, respectively. Because all 95 percent confidence intervals are plus or minus 2 percent, it is readily apparent that mean embeddedness in developed watersheds is greater than the other two groups. Partially developed and undeveloped watersheds cannot be distinguished with the level of precision used in this survey.

Embeddedness vs. Core Samples

Embeddedness measurements are significantly related to the amount of fine sediment analyzed from core samples.

The most heavily embedded spawning areas were Oxbow and Ice Hole with means of 39 percent (Fig. 3). The least embedded spawning areas were Corduroy and Burgdorf with means of 11 and 10 percent, respectively.

A one-way analysis of variance was used to determine whether the spawning areas were significantly different (Table 7). The probability that they are equal is equal to or less than 9 in 100,000 with 10 and 1267 degrees of freedom ($F = 23.35$). A least significant difference multiple range test (Table 8) shows that spawning areas of the upper South Fork at Oxbow, Glory, Poverty, and Stolle are significantly ($P = 0.05$) more embedded than spawning areas in the Secesh River, at Burgdorf, Courduroy, Secesh Bridge, and Chinook.

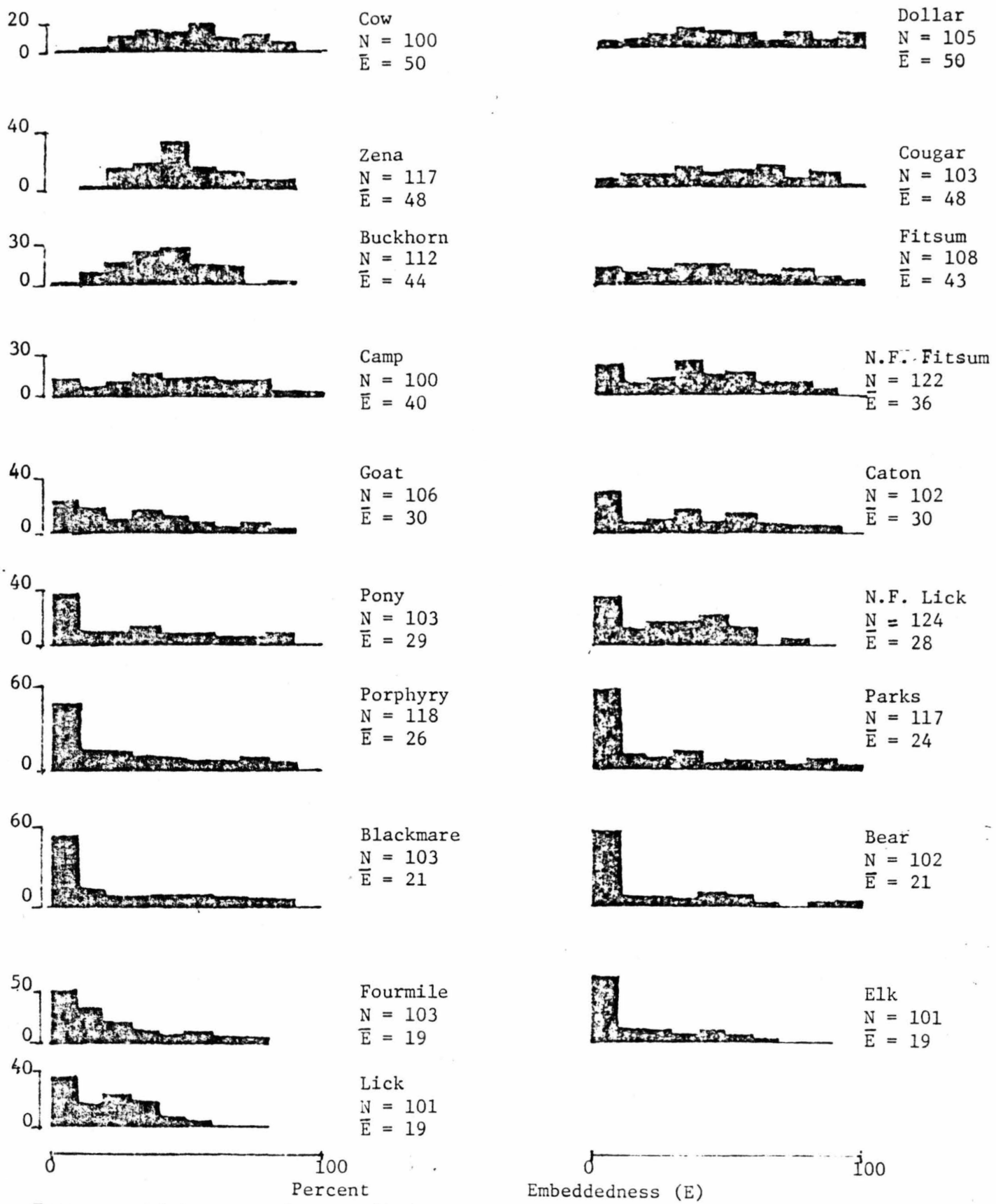

Figure 2. Frequency historgrams for embeddedness measurements taken in the South Fork Salmon River in 1983, from 19 tributary drainages with various levels of development. Locations with high embeddedness have nearly normal distribution of measurements.

Table 4. Tributary streams of the South Fork Salmon River ranged in mean embeddedness from 19 to 50 percent. The means were not equal (P = 0.00009) by a one-way analysis of variance.

Location	Mean	N	95% Confidence Internal For Mean
Dollar	50	105	45 to 56
Cow	50	100	46 to 54
Cougar	48	103	43 to 53
Zena	48	117	45 to 51
Fitsum	43	108	38 to 48
Buckhorn	41	112	38 to 44
Camp	40	100	35 to 45
N.F. Fitsum	36	122	32 to 40
Goat	30	106	27 to 35
Caton	30	102	25 to 35
Pony	29	103	23 to 35
N.F. Lick	28	124	24 to 31
Porphyry	26	117	21 to 31
Parks	24	117	19 to 30
Blackmare	21	103	16 to 26
Bear	21	102	16 to 26
Lick	19	101	16 to 23
Fourmile	19	103	15 to 23
Elk	19	101	14 to 23

Source	D.F.	Sum Squares	Mean Squares	F
Between Locations	18	245528.49	13640.47	23.66
Within Locations	2027	1168405.86	576.42	
Total	2045	1413934.34		

Table 5A. Least significant difference multiple range test for differences [illegible]een mean embeddedness (P = 0.05) of South Fork Salmon River tributaries [illegible]otes a significant difference) shows that undeveloped drainages. [illegible]urmile, Bear) are less embedded than developed drainages (Cow, Dollar).

Location	Mean	Elk	Fourmile	Lick	Bear	Blackmare	Parks	Prophyry	N.F. Lick	Pony	Caton	Goat	N.F. Fitsum	Camp	Buckhorn	Fitsum	Zena	Cougar	Cow	Dollar
Elk	19																			
Fourmile	19																			
Lick	19																			
Bear	21																			
Blackmare	21																			
[illegible]	24																			
[illegible]phyry	26	*	*	*																
N.F. Lick	28	*	*	*	*	*														
Pony	29	*	*	*	*	*														
Caton	30	*	*	*	*	*														
Goat	30	*	*	*	*	*														
N.F. Fitsum	36	*	*	*	*	*	*	*	*	*										
Camp	40	*	*	*	*	*	*	*	*	*	*	*								
Buckhorn	41	*	*	*	*	*	*	*	*	*	*	*								
Fitsum	43	*	*	*	*	*	*	*	*	*	*	*	*							
Zena	48	*	*	*	*	*	*	*	*	*	*	*	*	*						
Cougar	48	*	*	*	*	*	*	*	*	*	*	*	*	*						
Cow	50	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
[illegible]r	50	*	*	*	*	*	*	*	*	*	*	*	*	*	*					

Table 6. One-way analysis of variance among embeddedness values of developed, partially developed and undeveloped groups of South Fork Salmon River tributaries. Means for the groups are not equal (P = 0.00009).

Location	Mean	95% confidence Interval for Mean	N
Developed Group	44	42 to 46	867
Dollar	50		
Cow	50		
Cougar	48		
Zena	48		
Fitsum	43		
Buckhorn	41		
Camp	40		
N.F. Fitsum	36		
Part Developed Group	24	22 to 26	528
Goat	30		
Pony	29		
Parks	24		
Lick	19		
Elk	19		
Undeveloped Group	24	22 to 26	651
Caton	30		
N.F. Lick	28		
Porphyry	26		
Blackmare	21		
Bear	21		
Fourmile	19		

Source	Sum Squares	D.F.	Mean Square	F
Between groups	201901.58	2	100950.79	170.16
Within Groups	1212033.06	2043	593.26	

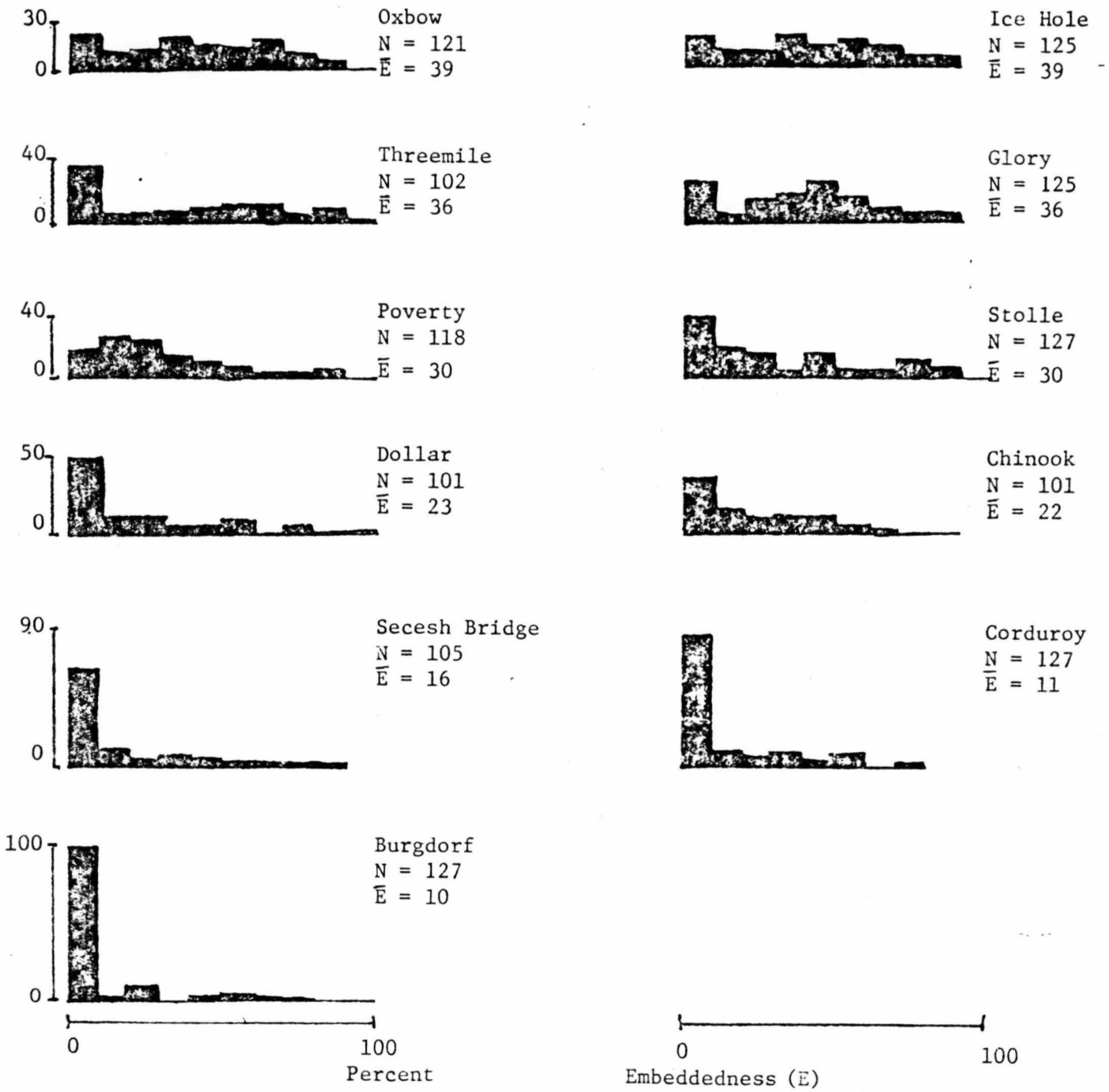

Figure 3. Frequency histograms for embeddedness measurements taken in the South Fork Salmon River in 1983, at 11 spawning areas show skewed distributions toward zero embeddedness when mean embeddedness is low.

Table 7. Spawning areas of the South Fork Salmon River ranged in mean embeddedness from 10 to 39 percent. The means were not equal (P = 0.00009) by a one-way analysis of variance.

Location	Mean	N	95% Confidence Internal for Mean
Ice Hole	39	125	35 to 44
Oxbow	39	121	34 to 44
Glory	36	125	31 to 40
Threemile	36	102	29 to 42
Poverty	30	118	26 to 34
Stolle	30	127	25 to 35
Dollar	23	101	17 to 28
Chinook	22	100	18 to 26
Secesh Bridge	16	105	11 to 20
Corduroy	11	127	8 to 15
Burgdorf	10	127	6 to 13

Source	D.F	Sum Squares	Mean Squares	F
Between Locations	10	143334.76	14333.48	23.35
Within Locations	1267	777617.37	613.75	
Total	1277	920952.13		

Table 8. A least significant difference multiple range test for differences between mean embeddedness (P = 0.05) of various spawning areas of the South Fork Salmon River shows that upper South Fork areas (Poverty, Oxbow, Glory) are more embedded than Secesh areas (Burgdorf, Corduroy, Secesh Bridge, Chinook). A significant difference between pairs is noted by an asterick.

Location	Mean	Burgdorf	Corduroy	Secesh Bridge	Chinook	Dollar	Stolle	Poverty	Threemile	Glory	Oxbow	Ice Hole
Burgdorf	10											
Curduroy	11											
Secesh Bridge	16											
Chinook	22	*	*									
Dollar	23	*	*	*								
Stolle	30	*	*	*	*	*						
Poverty	30	*	*	*	*	*						
Threemile	36	*	*	*	*	*						
Glory	36	*	*	*	*	*						
Oxbow	39	*	*	*	*	*	*	*				
Ice Hole	39	*	*	*	*	*	*	*				

A regression was run between the mean percent fine sediment (< 6.3mm diameter) from core samples at each location (Lund, 1982, Corley and Newberry, 1982) and mean embeddedness (Figure 4). Each data point represents 40 core samples and a minimum of 100 embeddedness measurements. The relationship accounts for 64 percent of the variation which is highly significant (P = 0.01, 9 degrees of freedom).

Monitoring Sources

Deposited fine sediment downstream of an open-pit mine was significantly greater than in control locations upstream or in adjacent drainages.

The highest level of mean embeddedness was 50 percent in Sugar Creek immediately downstream from the open-pit mine effluent from West End Creek (Figure 5). Mean embeddedness decreased to 42 percent in the East Fork immediately downstream from the confluence of Sugar Creek and further decreased to 22 percent in the East Fork immediately upstream from Vibika Creek. Upstream controls in Sugar Creek and the East Fork were 30 and 26 percent mean embeddedness, respectively. Controls in the adjacent drainages of Tamarack, Quartz, and Profile Creeks were 14, 14, and 10 percent mean embeddedness, respectively.

A one-way analysis of variance was conducted to determine whether mean embeddedness values for the various locations were significantly different (Table 9). The probability that the means are equal is equal to or less than 9 in 100,000 with 7 and 905 degrees of freedom (F = 34.40). A least significant difference multiple range test (Table 10) shows that the most heavily impacted areas of Sugar Creek downstream from West End Creek and the East Fork downstream from Sugar Creek are significantly (P = 0.05) more embedded than any of the controls.

Embeddedness vs. Free Matrix Particles

An incidental statistic available from this survey, the relative frequency of free matrix particles, is mathematically more sensitive than embeddedness over the range of sample means. Measurement in the field is less subject to systematic error, or bias, because it is an absolute determination.

Where the measurement d_2 equals zero then E = 0. This yields a binomial statistic. When the number of measurements where E = 0 is divided by the total number of samples, the result is an estimate of the relative frequency of absolutely unembedded or free matrix particles (Table 11).

Free matrix particles range from 0 to 77 percent for the 38 locations sampled. For these same locations, mean embeddedness only ranged from 10 to 50 percent.

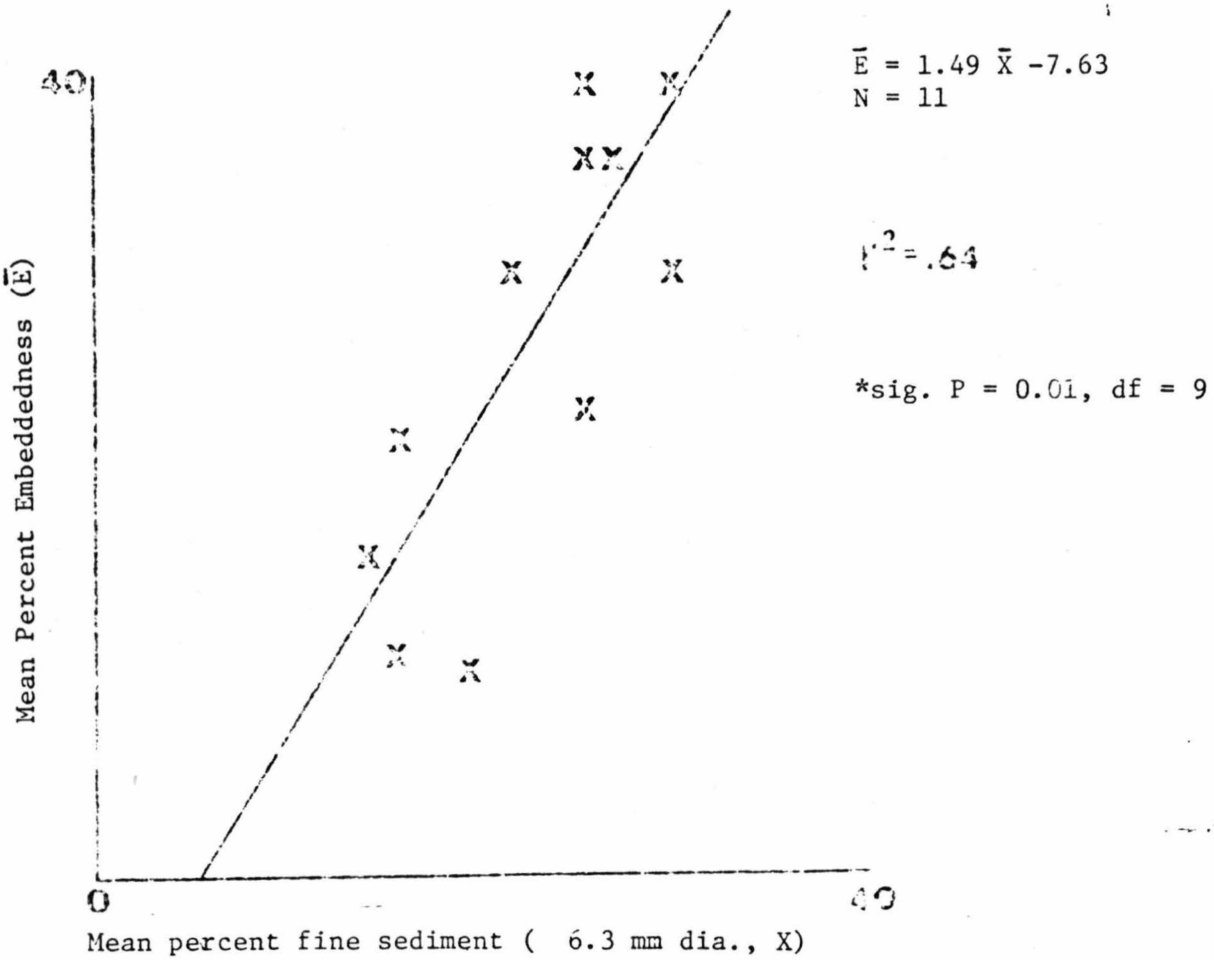

Figure 4. A regression between the mean percent fine sediment from core samples (Lund, 1982, Corley and Newberry, 1982) collected 1981 ($\bar{X}$) and mean percent embeddedness ($\bar{E}$) collected in 1983 from 11 locations in the South Fork Salmon River accounts for 64 percent of the observed variation. Each data point represents a mean derived from 40 cores samples and a mean derived from a minimum of 100 embeddedness measurements.

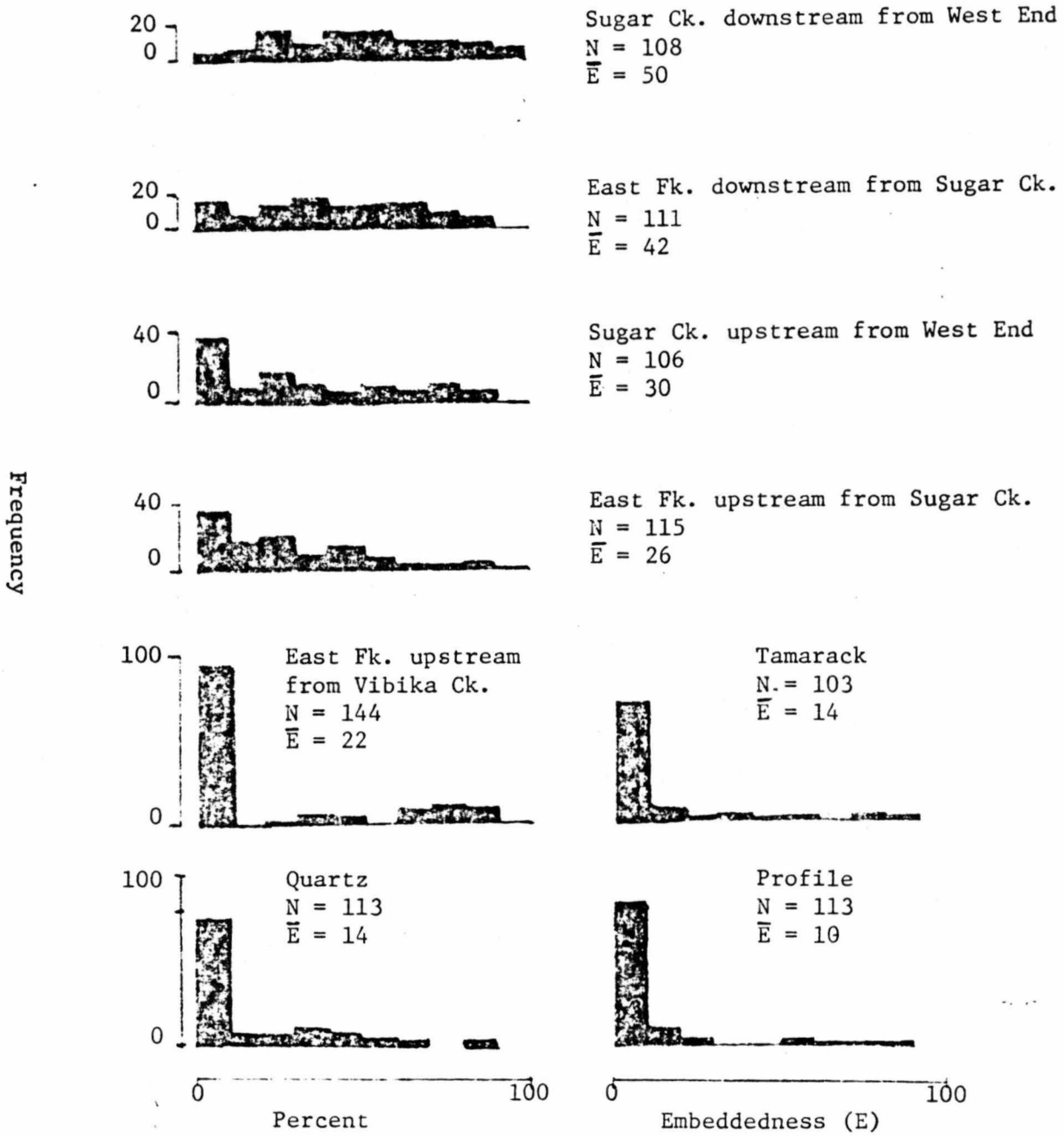

Figure 5. Frequency histograms for embeddedness measurements taken in the South Fork Salmon River in 1983, in the East Fork around on open-pit mine in West End Creek, show skewed distributions toward zero for controls in Quartz, Profile, and Tamarack Creek. Immediately downstream from the source of sediment (top) distribution is near normal about a mean of 50 percent.

Table 9. A one-way analysis of variance among mean embeddedness values of sites in the East Fork of the South Fork of the Salmon River surrounding the open-pit mine in West End Creek, showed that the means were not equal (P = 0.00009).

Location	Mean	N	95% Confidence Internal for Mean
Sugar Creek downstream from West End	50	108	46 to 55
East Fork downstream from Sugar Creek	42	111	37 to 47
Sugar Creek upstream from West End	30	106	25 to 36
East Fork upstream from Sugar Creek	26	115	22 to 31
East Fork upstream from Vibika Creek	22	144	17 to 27
Tamarack Creek	14	103	9 to 19
Quartz Creek	14	113	10 to 17
Profile Creek	10	113	6 to 14

Source	D.F.	Sum Squares	Mean Squares	F
Between Locations	7	159006.08	22715.15	34.40
Within Locations	905	597603.66	660.34	
Total	912	756609.73		

Table 10. A least significant difference multiple range test for differences between mean embeddedness (P = 0.05) of sites in the East Fork of the South Fork Salmon River surrounding an open-pit mine in West End Creek, showed significantly more embeddedness immediately downstream from the mine than in upstream controls or controls in adjacent watersheds. A significant difference is noted by an asterisk.

Location	Mean	Profile	Quartz	Tamarack	East Fork Upstream From Vibika Creek	East Fork Upstream From Sugar Creek	Sugar Creek Upstream From West End	East Fork Downstream From Sugar Creek	Sugar Creek Downstream From West End
1/ Profile	10								
1/ Quartz	14								
1/ Tamarack	14								
2/ East Fk upstream from Vibika Creek	22	*	*	*					
3/ East Fk. upstream from Sugar Creek	26	*	*	*					
3/ Sugar Creek upstream from West End	30	*	*	*	*				
4/ East Fk. downstream from Sugar Creek	42	*	*	*	*	*	*		
4/ Sugar Creek downstream from West End	50	*	*	*	*	*	*	*	

1/ Controls in adjacent drainages
2/ Several kilometers downriver from source
3/ Upstream controls
4/ Immediately downstream from source

A regression was completed between the percent of free matrix particles observed at each location where mean embeddedness was estimated (Figure 6). The relationship accounts for 82 percent of the observed variation and is highly significant (P = 0.01, 36 degrees of freedom). The embeddedness intercept near 45 percent indicates that the measurement of free matrix particles would not be a good monitoring tool in heavily embedded streams. The free matrix particle intercept should theoretically be at M = 100, E = 0. This would be a greater range of percentages than for observed embeddedness. Utilizing free matrix particles as an indicator of fine sediment deposition in relatively clean streams should be a mathematically more sensitive monitoring tool than estimation of embeddedness.

Table 11. In the South Fork Salmon River the relative frequency of free matrix particles ranged from 0 to 77 percent. This binomial statistic is determined by counting free matrix particles and dividing by the sample size.

Location	Number of Free Matrix Particles (No)	N	Relative Frequency of Free Matrix Particles M = $\frac{No}{N}$ (100)	95% Confidence Interval for M
Developed, Part Developed and Undeveloped Tributaries				
Dollar	5	105	5	1 to 9
Cow	2	100	2	-1 to 5
Cougar	5	103	5	1 to 9
Zena	0	117	0	-
Buckhorn	0	112	0	-
Fitsum	11	108	10	5 to 15
Camp	12	100	12	6 to 18
N.F. Fitsum	18	122	15	9 to 21
Goat	19	106	18	10 to 26
Caton	27	102	26	18 to 34
Pony	35	103	34	25 to 43
N.F. Lick	30	124	24	16 to 32
Porphyry	39	117	33	25 to 41
Parks	42	117	36	27 to 45
Blackmare	38	103	37	28 to 46
Bear	51	102	50	40 to 60
Lick	32	101	32	23 to 41
Fourmile	28	103	27	18 to 36
Elk	40	101	40	30 to 50
Spawning Areas				
Oxbow	19	121	16	10 to 22
Ice Hole	16	125	13	7 to 19
Glory	25	125	20	13 to 27
Threemile	36	102	35	26 to 44
Poverty	11	118	9	4 to 14
Stolle	34	127	27	19 to 35
Dollar	43	101	43	33 to 53
Chinook	31	100	31	22 to 40
Secesh Bridge	55	105	52	42 to 62
Corduroy	86	127	68	60 to 76
Burgdorf	98	127	77	70 to 84

Table 11 (Cont)

Location	Number of Free Matrix Particles (No)	N	Relative Frequency of Free Matrix Particles M = $\frac{No}{N}$ (100)	95% Confidence Interval for M
East Fork of South Fork				
Sugar Creek Downstream from West End	2	108	2	-1 to 5
East Fork Downstream from Sugar Creek	14	111	13	7 to 19
Sugar Creek Upstream from West End	34	106	32	23 to 41
East Fork Upstream from Sugar Creek	33	115	29	21 to 37
East Fork Upstream from Vibika Creek	93	144	65	57 to 73
Quartz	71	113	63	54 to 72
Tamarack	68	103	66	57 to 75
Profile	80	113	71	63 to 79

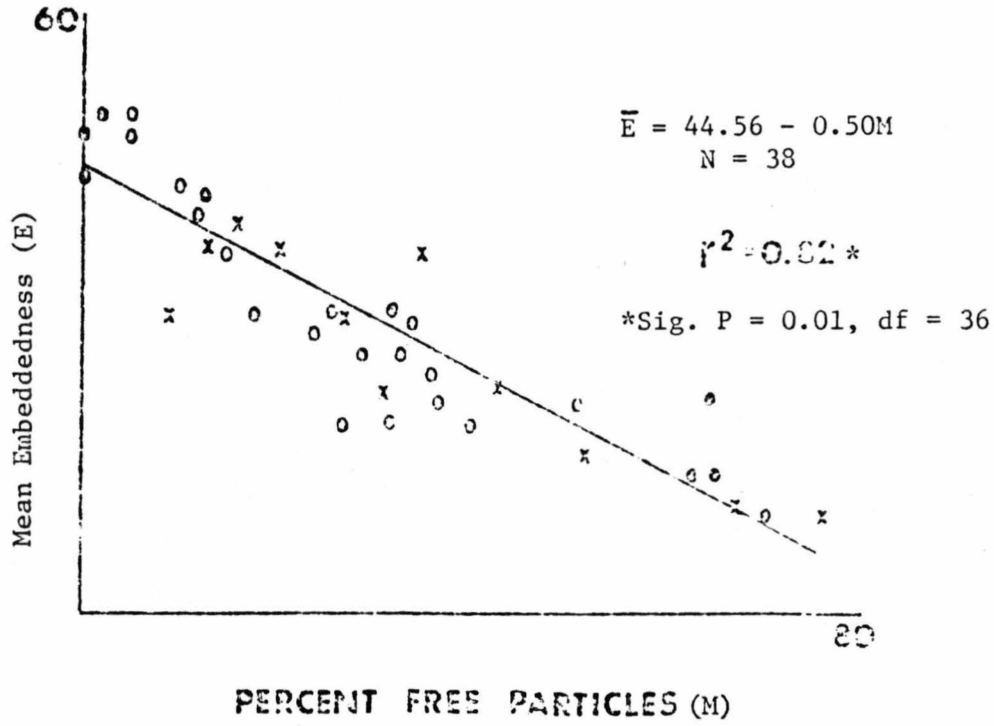

Figure 6. A regression between the relative frequency of free matrix particles and the mean percent embeddedness from 38 locations in the South Fork Salmon River in 1983, accounts for 82 percent of the observed variation. Solid circles represent locations in the East Fork, X's represent spawning locations and circles represent developed, partially developed and undeveloped tributaries.

DISCUSSION

Developed vs. Undeveloped

The analysis supports a conclusion that a "threshold" of development exists such that no detectable deposition or embeddedness results in the surveyed fish habitats. This study does not quantify that "threshold" of development. The relationship between embeddedness and other variables such as sediment yield, water yield, drainage size and/or road mileage must be analyzed before an empirically justifiable threshold can be identified. Stowell, Espinosa, Bjornn, Platts, Burns, and Irving (in press) reported similar analyses based on embeddedness.

Just because a quantitative development threshold could be defined in terms of protecting fish habitat, does not mean that development should occur. Other environmental values lost to development, like wilderness and spiritual sanctuary, must be considered. Someone will have to decide how much development should occur.

The definition of the "threshold" from empirical evidence takes on added significance based on other results of this survey. Streams located within watersheds which were heavily roaded in the 1950's and 1960's are still significantly more embedded than undisturbed areas. The loss of fish rearing capacity per unit increase in embeddedness is the greatest from zero to about 50 percent embeddedness (Kamt, 1976, Kelly and Dettman, 1980). The difference between undeveloped or partially developed watersheds at 24 percent embeddedness and developed areas at 44 percent, occurs in this area of the greatest fish habitat loss per unit increase in embeddedness. The empirical evidence indicates that recovery of fish habitat to undisturbed condition after heavy development of a watershed does not occur after 10 to 20 years, even with an extensive reclamation program discussed by Megahan, Platts, and Kulesza (1980). Additionally, most of the recovery of fish habitat has yet to occur after 10 to 20 years. Because of the size of matrix particles it would take significant energy, a significant storm, to move the armour. There is no evidence that long-term development constraints, which assume total or near total recovery during 10 to 20 years, adequately protect fish habitat.

More analysis is needed to identify development constraints which do not put fish habitat at significant risk.

Embeddedness vs. Core Samples

The significance of the relationship between measured embeddedness and core samples is strong enough to suggest that embeddedness measures the quantity of interstitial fine sediment in fish habitats. Three sources of variation not taken into account in this text are; 1) core samples are from 1981 and embeddedness measurements from 1983, 2) differences in matrix particle size are observable between locations and 3) embeddedness was measured adjacent to core sampling areas but not in them.

Embeddedness should be related to 1983 core samples, as data becomes available.

Embeddedness of spawning areas should not be directly compared to other estimates in this survey because of difference in velocity and depth criteria. The degree of relationship is not strong enough to suggest that core sampling can be replaced by embeddedness measurements.

Monitoring Sources

The results are strong indication that monitoring of individual projects or potential sources of sediment can be successful by using networks of measurements. The magnitude of impact can be estimated as well as its extent downstream.

Future projects in the South Fork could be monitored utilizing a system of before - after, upstream - downstream, and control techniques. Sampling time is not excessive. Field time ranged from ½ hour to 1 hour per site in this study once streamside was reached. About six locations could be measured per day where sites are accessible by road.

Embeddedness vs. Free Matrix Particles

Contact should be made with researchers to investigate a direct linkage between measurement of free matrix particles and fish carrying capacity of the habitat. Free matrix particles are mathematically more sensitive than embeddedness measurements, where embeddedness is between zero and about 50 percent. This could be important from the standpoint of monitoring sensitivity in the embeddedness range where the most significant fish habitat losses can occur.

MANAGEMENT RECOMMENDATIONS

1) Conduct an interdisciplinary analysis to relate embeddedness to estimated sediment yield, drainage size, road mileage, and other significant factors. Define an empirically based development constraint from such an analysis.

2) Relate 1983 embeddedness to 1983 core samples as data becomes available.

3) Project monitoring plans should contain provisions for measuring embeddedness.

4) Contact researchers to develop a direct linkage between free matrix particles and salmonid rearing capacity.

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